Summary of the Second Meeting of the Science Team Studying the Radiative Impact of Aerosols on Climate

The Global Aerosol Climatology Project (GACP) was established in 1998 to analyze existing satellite radiances, field experiment and surface measurements in order to infer the global distribution of aerosols, their properties, and their seasonal and interannual variations. A science team was also formed through a competitive announcement in 1998, to study the radiative impact of aerosols on climate. Data sets and analyses generated by GACP are used by the science team in studying the radiative impact of aerosols, to improve understanding and to stimulate the development of climate models which include the effects of aerosols.

The second meeting of the aerosol science team took place on 29 September through 1 October, 1999, at the NASA Goddard Institute for Space Studies in New York City. Most of the 32 investigations funded by NASA's Radiation Science Program were represented at this meeting. In addition, approximately fifteen US and international team members whose work is supported by other means, participated in the meeting. The total number of participants in the 2 1/2 day meeting was approximately 65 to 70. The following is a brief summary of the meeting.

This second aerosol science team meeting had two primary objectives: 1) discussion of recently conducted aerosol model inter-comparisons, and 2) discussion of the availability and characteristics of data sets to be used in these aerosol studies. The presentations included a number of team member progress reports. Additional team member reports are to be given in a special session of the Fall 1999 Meeting of the American Geophysical Union (San Francisco, 13-17 December, 1999). First year progress reports of each of the science team member investigations are available on the web at the following URL: http://gacp.giss.nasa.gov/science_team/

Meeting Report

Modeling of Global Climatologies

It was decided at the first aerosol science team meeting that due to the closely aligned interests of IPCC 2001 and the activities of the modeling portion of the present science team, it would be useful for relevant team members to participate in the IPCC model inter-comparison. The objective of the IPCC model inter-comparison was to examine the capability of global models to represent the amounts and distribution of a wide suite of aerosol components. Ten aerosol models participated in the model inter-comparison study. An overview of the results of the inter-comparison was given by J. Penner followed by the results of five individual study participants who are also science team members. The five model studies are identified by the specific global model, contributor, aerosol component (OC= organic carbon, BC = black carbon) and type of forcing considered, in the following table:

Model	Contributor	Aerosol component treated	Forcing
LLNL/U. Mich.	Chuang	sulfate, OC, BC, dust, sea salt	indirect
U. Michigan	Herzog	sulfate, OC, BC, dust, sea salt	direct
NASA/GISS	Koch	sulfate, OC, BC, dust, sea salt	direct, indirect
NASA/GSFC	Chin	sulfate, OC, BC, dust, sea salt	
ECHAM/Dalhousie	Lohman	sulfate, OC, BC	indirect

Eight scenarios were defined for present day and future aerosol emissions. Like previous model inter-comparisons, the IPCC study showed vast differences in model prediction of the vertical distribution of aerosols. These differences are mainly the result of differences in vertical transport of both SO2 and aerosol sulfate coupled with differences in the scavenging by precipitation associated with transport. For comparison with the models, observations were provided by Savoie and Prospero at a number of locations. Despite the variability in vertical distribution, however, the models did a reasonable job of simulating aerosol sulfate at most remote surface sites. In contrast to sulfate, the IPCC comparison for other aerosol types showed that the capability for models to treat these components is relatively inferior to sulfate aerosol. The overall sea salt fluxes are uncertain by at least a factor of two. For dust in the northern hemisphere, the two NASA models were consistently higher than observations where the Hadley model was too low. It was decided that this comparison should be re-evaluated using predicted surface concentrations from all the models (rather than the average concentrations from 0 – 2 km, as originally specified). Interpretation of the comparison of observed and model-predicted concentrations for both organic carbon and black carbon is relatively more difficult because of both inaccuracies in the observations due to poorly quantified analytical techniques and the fact that measured concentrations are only available on a field campaign basis. In addition, the source strength of these compounds is more poorly known. Despite these difficulties, most models were able to reproduce the observed concentrations of BC to within a factor of 10 and some (NASA models) were consistently better than a factor of 10. The comparison of measured and predicted OC were less satisfactory.

Results of calculations of the globally averaged annual mean radiative forcing available at the time of the meeting are as follows:

Direct Forcing in Wm^{-2} (2000 scenario)

Model	SO4	BC	OC	Total
NASA/GISS	-0.66	0.51	-0.29	-0.44
Hadley	-0.18	0.13		

Indirect Forcing in Wm^{-2} (2000 scenario)

Model	Shortwave Forcing
LLNL/U. Mich.	-0.73
NASA/GISS	-1.56
ECHAM/Dalhousie	-0.30

As part of the IPCC 2001 study several future scenarios were also developed. Some of the results of these future scenarios were presented and discussed at the meeting. These results are summarized in a paper by Penner and Zhang, submitted for presentation at the annual meeting of American Meteorological Society, January, 2000.

Preliminary comparison of model results with ERBE clear-sky reflectance was provided by Brian Soden, GFDL. For this comparison, the model results were described in terms of columnar mass loading, and these were used to derive predicted reflectance. There were significant differences in the model's ability to reproduce the reflectances. All of the models compared thus far showed the tendency to over-predict reflected radiation at the higher latitudes in the northern hemisphere (poleward of 30°N). Brian discussed the possible causes of this bias (as well as a bias towards and under-prediction of reflectance in the Southern Hemisphere that is present in some of the models), but he has not been able to identify any specific cause of these biases (other than the possible need for changing the aerosol amounts).

Modeling of Aerosol Radiative Forcing

The aerosol radiative forcing discussion was initiated by V. Ramaswamy, who, unofficially, reviewed the status of IPCC considerations of the status of understanding of global radiative forcings. The well-mixed greenhouse gases are known to cause a radiative forcing of about 2.4 Wm^{-2} , with about 10 percent uncertainty. Understanding of ozone radiative forcing, with troposheric ozone increase causing a warming, and lower stratospheric ozone depletion causing a cooling, is firmer than five years ago. But aerosol direct and indirect forcings remain very uncertain, mainly because of uncertainties in how the many different aerosol components (compositions) are changing and because of their uncertain effects on cloud properties. Narrowing the uncertainties will require a coordinated research program including global observations of aerosol microphysical properties, global modeling of aerosol distributions and their influence on clouds, in situ studies of the influence of aerosols on cloud processes, and regional field studies of aerosol effects. Concepts for in situ studies of the aerosol and cloud processes were discussed by J. Brengueir. A. Del Genio presented preliminary 3-D studies of the indirect aerosol forcings by sulfate aerosols, finding substantial forcing due to both the Twomey (albedo) effect (about 1 Wm^{-2}) and the cloud lifetime (cloud cover) effect (more than 1 Wm^{-2}). Bergstrom presented evidence of large regional direct radiative effects of aerosols over the North Atlantic Ocean.

Modeling - IPCC Chemistry Inter-comparison

The atmospheric chemistry chapter of the IPCC's Third Assessment Report (TAR) initiated a modeling effort to evaluate the IPCC scenarios (of projected future emissions) for changes in tropospheric ozone as a greenhouse gas and in the oxidative capacity of the troposphere (as measured by the CH4 budget). The focus of this modeling effort - called OxComp - was to evaluate the different 3-D global chemistry-transport models (CTM) within a common framework and to build a consensus on current tropospheric modeling capability to predict changes in OH and O3 in response to changing emissions. As a secondary goal of OxComp, we need to build a practical parameterization to calculate the chemically active greenhouse gases for the range of IPCC SRES scenarios. The initial OxComp workshop was held coincident with the aerosol chapter's modeling workshop in Hamburg, 15-17 July 1999. The different model studies requested were: (1) Yr-2000 reference atmosphere (a new standard atmosphere with models to be compared with O3 measurements from surface and sondes, and CO measurements from a few surface sites); (1a) delta-CH4, Yr-2000 with CH4 concentration increase by +10%; (2) Yr-2100 atmosphere (SRES A2); (2a) Yr-2100 with low NOx emissions; (2b) Yr-2100 with low NOx+CH4+NMHC emissions (high CO, like SRES A1); (3) Yr-2100 plus changes in 'natural' emissions for 2100 climate; (4) Yr-2100 (SRES A2) plus atmospheric changes (T, q, convection) for the 2100 climate. Case (3) will be done off line as the changes in natural emissions were not ready. Case (4) will only be done by 2 groups at most, but shows a large feedback of climate change on tropospheric ozone (reducing it). The focus of the intercomparison is on case (1), which can be compared with current measurements (CO and O3), and on case (2), which represents the extreme case of largest NOx, CH4, and CO emissions. The changes in ozone for (2)-(1) vary greatly from model to model, especially when one looks for where in the free troposphere the excess ozone accumulates. The global mean change in O3 for these models is more consistent. The predicted change, 21 ± 5 DU, is more than twice as large as that estimated for the change from pre-industrial to present. These results need further evaluation.

Data Sets from Satellite Aerosol Retrievals

The satellite and model global climatologies discussion was initiated by Larry Stowe who summarized the characteristics of the NOAA operational aerosol product derived using AVHRR channel-1 radiances and briefly described its use in many aerosol studies. Terry Nakajima and Akiko Higurashi described their research aimed at improving AVHRR retrievals by utilizing AVHRR channel-2, as well as channel-1 radiances and pointed out significant potential differences between their global optical thickness value and that derived by Stowe. Nakajima also described preliminary results of a simultaneous analysis of AVHRR cloud and aerosol retrievals potentially showing the signature of the indirect aerosol effect. Mike Mishchenko summarized the results of an extensive sensitivity study of aerosol retrievals using two-channel radiance data and introduced a preliminary climatology of aerosol optical thickness and Angstrom exponent for the period of NOAA-9 observations. He singled out radiance calibration and cloud screening as major issues that need to be addressed before attempting a global aerosol climatology for the full period of satellite data. Phil Durkee described his advanced multi-channel and multi-satellite retrievals of aerosol properties and their extensive validation versus in situ and ground-based data obtained during various field campaigns. He specifically discussed the advantages of adding multiple view angles by using multi-satellite data. He also advocated the preparation of a comprehensive data set for validation of retrieval algorithms developed by the Science Team. Omar Torres described the current status of aerosol retrievals based on using TOMS short-wave radiance data and significant attempts to make the TOMS product more quantitative and accurate. He pointed on large areas in the southern hemisphere with potentially large aerosol loads. Philippe Goloub described the results of advanced aerosol retrievals using POLDER radiance and polarization data. He demonstrated the significant sensitivity of polarization to aerosol microphysical characteristics and the resulting improvement of the accuracy of aerosol retrievals using polarization as well as radiance measurements. He specifically described impressive applications of the polarization retrieval technique to aerosols over land. The global climatologies session was summarized by Joyce Penner and Phil Durkee and concluded by an extensive panel discussion of immediate needs and short-term and long-term plans. The discussion was moderated by Phil Durkee and Ralph Kahn.

Data Sets from Process and Closure Studies

Harshvardhan chaired the session which reviewed the results of a variety of process and closure studies. Ship board measurements of aerosols were discussed by Patricia Quinn. This data set includes measurements in the Pacific and the Atlantic Oceans. The latter were associated with the closure studies in the North Atlantic Aerosol Characterization Experiment (ACE 2). Status of the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) data set was discussed by Phil Russell. TARFOX was a closure field study geographically oriented in the northwestern Atlantic region. Aerosol profile data sets from airborne and ground-based lidar measurements were discussed by Rich Ferrare. These data sets include a number of missions over 3 continents and 3 oceans. Preliminary results of the Indian Ocean Experiment (INDOEX) were discussed by Jim Coakley and Tony Clarke. In addition to the airborne measurements in INDOEX, Clarke discussed the large data set he has developed from previous campaigns around the world. Process and closure study measurements discussed in this session are summarized in a set of tables provided by the presenters and placed on the GACP web site.

Data Sets - Extended Spatial and/or Temporal Coverage

Five extended coverage (spatial or temporal) data sets were presented in this session, including two data sets on aerosol optical depth (one globally-distributed, one continental U.S.), one long-term climatology of vertical profiles of aerosol backscattering in Southern California, one data set providing in-situ measurements of aerosol radiative properties at a variety of sites (mostly in North America), and one literature survey of aerosol chemical measurements that include determination of carbonaceous aerosols. In the discussion, the use of these extended data sets in developing a global aerosol climatology, it was suggested to derive frequency distributions of aerosol radiative properties, such as single-scattering albedo, stratified by an independent parameter, such as aerosol optical depth. Such an approach would allow a direct comparison of statistical distributions derived from models, in-situ measurements, satellite remote sensing, and ground-based remote sensing. The discussion identified the need to form focussed topic teams to pursue such multi-faceted comparisons.

Data Sets - Radiation Budget Quantities

A large number of radiation budget data sets exist for studies of the radiative impact of aerosols. Such data sets include broad band shortwave (SW), top of the atmosphere (TOA) irradiances from ERB, ERBE, ScaRaB, and CERES. Surface radiation budget (SRB) data sets are presently available from the globally derived WCRP-SRB retrievals, and measurements made in cooperation with the geographically distributed GEBA and BSRN networks. A well calibrated data set is also evolving from the DOE/ARM sites. A historical data set starting about 1960 is also available for some sites in Germany operated by the German Weather Service (DWD). In addition to broadband SW measurements, spectral irradiance data sets are available from a number of field experiments. In this session, the identified field studies included surface level spectral irradiance measurements made by Peter Pilewskie in SUCCESS, FIRE III Arctic Cloud Experiment and several smaller field deployments.

The utility of radiation budget data sets in understanding the radiative impact of aerosols is demonstrated in their quantitative comparison with aerosol optical depth (AOD). Even if the uncertainty in broadband ERB TOA data (global mean over tropics) is not better than 4 Wm^{-2}, the stability (precision) of the observed year-to-year change is much better (~1 Wm^{-2} for ERBE and smaller still for CERES). It is concluded that existing ERB data sets, as listed above, can be used with GACP AOD and other data to derive useful estimates of the radiative impact of aerosols.

Uncertainties in surface measurements of broadband irradiance

Several data sets are available giving surface measurements of broadband shortwave irradiance at a variety of geographically distributed locations. These include: GEBA, BSRN, SurfRad, USDA UVB Radiation Monitoring, and MFRSR amongst several others. The recent development of the DOE/Atmospheric Radiation Measurement sites offer excellent measurements at a few locations and only in recent years. Web sites for these data sets are given below. The most extensive data set in terms of the number of surface sites (~1000) and length of record (30 or more years in some cases) is the Global Energy Budget Archive (GEBA) data set. However, most commonly the measurements archived are monthly averages. This data set is also difficult to characterize in terms of absolute accuracy and precision. The more recent Baseline Surface Radiation Network (BSRN), does not have as many sites (approx. 24) but does have better documentation and, possibly more importantly for the present application, the temporal resolution of this archive is from 1 to 5 minutes. The BSRN data set is limited to the last 8 years giving only limited overlap with the GACP interests of the last 20 years.

Inherent and known uncertainties associated with the best maintained broadband shortwave irradiance instruments have a minimum of 1% to 2% corresponding to a minimum radiometric uncertainty of 10 to 20 Wm^{-2}. A concern noted in several of the discussions was with the lack of auxiliary information at the time of the irradiance measurement, needed to characterize the uncertainties in the measurements. Several correction approaches are being studied. The uncertainty which this potential error source causes strongly affects the use of these data in aerosol radiation studies. The most useful data sets for studies of the radiation impact of aerosols, are obviously those in which knowledge of the measurement error sources is most certain.

Surface based shortwave irradiance measurements continue in several cases, to exhibit incompatibilities with radiation transfer models. Calculations for the diffuse irradiance are found to exceed measurements by about 10 to 15 Wm^{-2}. When reasonable values of aerosol single scattering albedo (ω_o) are used, the discrepancy between computed and measured insolation is not reduced to zero. This is in contrast to some surface based shortwave radiometer measurements and airborne campaigns, where general agreement between measurements and calculations were reported.

Sample web sites for measurements of shortwave irradiance at the surface

BSRN - http://bsrn.ethz.ch/
GEBA - http://bsrn.ethz.ch/gebadoc/geba_home.html
MFRSR - http://hog.asrc.cestm.albany.edu/
SurfRad - http://www.srrb.noaa.gov/
USDA UVB Rad. Mon. - http://uvb.nrel.colostate.edu/UVB/home_page.html

Differences between measurements and calculations of solar spectral irradiance

Moderate resolution (5-15 nm) spectra of the downwelling solar irradiance at the ground in north central Oklahoma were measured during the DOE/ARM Intensive Observation Period in the fall of 1997. Spectra obtained under cloud-free conditions were compared with calculations using a coarse resolution radiative transfer model to examine the dependency on model-measurement bias on water vapor. It was found that the bias was highly correlated with water vapor and increased at a rate of 9 Wm^{-2} per cm of water, with the greatest contribution coming from the mid-visible portion of the spectrum. The source of the discrepancy remains undetermined because of the complex dependencies of other variables, most notably aerosol optical depth (which was measured and used in the model calculations), on water vapor. A compelling aspect of this analysis is that by focusing on the variability of the discrepancy with water vapor, rather than on the magnitude of the discrepancy, measurement (or model) uncertainty is less significant than it would be if we were assessing the level of agreement for, say, a single spectrum. Although the difference between measurement and model for nearly all of 2500 cases analyzed was well within the estimated 5% uncertainty, over the wide range in column water (a factor of five increase during the experiment) the difference becomes substantial, almost 40 Wm-2 for the integrated broadband.

Results of analyses using broadband solar irradiances

Despite the uncertainties in the broadband flux measurements much can be learned from the systematic study and analysis of these measurements due to their longevity. Looking at the historical data, the DWD long term clear sky observations show a clear trend for a decrease in surface insolation of about 10 Wm^{-2} over the last three decades. Strong effort was applied to avoid cloud contamination in the clear sky insolation data. Additionally, the surface sites of the DWD are characterized as extremely well calibrated and very well maintained. An early version of the WCRP/GEWEX SRB data set derived solely from satellite measurements showed disagreements with selected African broadband solar measurement sites that exceeded 80 Wm^{-2} in locations and seasons of biomass. At times of reduced biomass burning, differences are smaller than 10 Wm^{-2}. These discrepancies are far larger than the uncertainties of the measurements and therefore constitute an important part of the historical aerosol radiative forcing record. Research into accounting for these biomass burning anomalies continues by using remote sensing analysis to locate fires in the tropics (using high resolution night-time visible radiances) and smoke over dark surfaces in the middle latitudes (using AVHRR radiances). Trajectory modeling analysis is being used to approximate the subsequent distribution of their smoke plumes.

It was summarized that more emphasis needs to be placed on ω_0 that is a critical parameter in radiation studies concerning the radiative effect of cloud and aerosol. Studies of new interpretation techniques for AERONET observations hold some promise, At present, satellite-based aerosol products lacks such information. The bulk value of ω_0 in the entire atmospheric column may be derived by combining well-calibrated satellite and ground based spectral and broadband measurements. However at present, the only hope to derive a global ω_0 data set of usable accuracy seems to be based on chemical model simulation and atmospheric stratification, constrained by field observations.

Future Plans

Future plans regarding advanced satellite retrievals were discussed during the last session of the science team meeting as well as during a 1-hour workshop of the satellite retrievals working group formed at the meeting. It is planned that the working group will perform a detailed comparison of retrieval algorithms developed by Larry Stowe, Terry Nakajima, Phil Durkee, and Mike Mishchenko. The initial activity will focus on comparing radiance calibrations of the first and second AVHRR channels, cloud screening algorithms, and the statistical characteristics of the radiance fields entering the satellite retrievals.

Additional future plans relevant to aerosols in radiation budget include:

- Coherent listing of satellite and surface resources for broadband SW observations (historical and contemporary) on the web.
- We request an international protocol for measurement of AOD that is comparable to the WMO BSRN protocol for broadband radiation.
- Will draft consensus statement on the discrepancy of measurements and calculations for clear sky broadband (i.e., surface based comparisons have discrepancies but some airborne campaigns don't see them).